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NEURAL NETWORK CLASSIFICATION OF EEG USING CHAOTIC PREPROCESSING AND PHASE SPACE RECONSTRUCTION (U)

Capt David Tumey
Lt Col Paul E. Morton

Armstrong Aerospace Medical Research Laboratory

David F. Ingle
Craig W. Downey
John H. Schnurer

Logicon Technical Services, Inc.
P.O. Box 317258
Dayton OH 45431-7258

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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

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TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Kenneth R Boff

KENNETH R. BOFF, PhD, Chief
Human Engineering Division
Crew Systems Directorate
Armstrong Laboratory

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David F. Ingle*, Craig W. Downey*, John H. Schnurer*

ORGANIZATION NUMBER

Logicon Technical Services, Inc.
PO Box 317258
Dayton OH 45431-7258

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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Human Engineering Division, AFSC, HSD
Wright-Patterson AFB OH 45433-6573

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MENTARY

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Researchers have long focussed on using physiological measures as an indicator of mental workload. Research with transient and steady state evoked potential electroencephalograph (EEG) signals has provided the basis for further study in mental state estimation. Studies involving sum-of-sines steady state evoked potentials have demonstrated a correlation between spectral changes and changing cognitive workload. It has also been found that subjects can learn to control their responses to steady state visual stimulus, provided near-real-time performance information was fed back to them in such a way as to close the loop encompassing the subjects and the stimulus. With the emergence of new sciences such as Artificial Neural Systems and Chaotic theory, the possibility of achieving a rudimentary form of automatic cognitive state estimation or "Cognitive Mode Mapping" has presented itself. Using these powerful analysis tools, the authors are developing a system that analyzes and classifies EEG data from four sites of a subject's brain. The subjects produce this data while performing five selected cognitive tasks. The objective of the Cognitive Mode Mapping system is to identify the tasks based on salient features embedded in the raw EEG signals.

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NEURAL NETWORK CLASSIFICATION OF EEG USING CHAOTIC PREPROCESSING AND PHASE SPACE RECONSTRUCTION

David M. Tumey, Capt, USAF, Paul E. Morton, M.D., Ph.D., LtCol, USAF
AAMRL/HEG, Wright Patterson Air Force Base, Dayton, Ohio 45433

David F. Ingle, Craig W. Downey, John H. Schnurer
Logicon Technical Services Inc., Dayton, Ohio 45440

Abstract

For many years, researchers have focussed on utilizing physiological measures as an indicator of mental workload. Research involving transient and steady state evoked potential electroencephalograph (EEG) signals has provided the foundation for further study in mental state estimation. Studies involving sum-of-sines steady state evoked potentials have demonstrated a correlation between spectral changes and changing cognitive workload. In addition, it has been found that subjects can learn to control their responses to steady state visual stimulus, provided near-real-time performance information was fed back to them in such a way as to effectively close the loop encompassing the subjects and the stimulus. With the recent emergence of new sciences such as Artificial Neural Systems and Chaotic theory, the possibility of achieving a rudimentary form of automatic cognitive state estimation or "Cognitive Mode Mapping" has presented itself. By utilizing these powerful analysis tools, the authors are developing a system that analyzes and classifies EEG data recorded from four sites of a subject's brain. The subjects produce this EEG data while performing five selected cognitive tasks. The objective of the Cognitive Mode Mapping system is to identify these tasks based on the salient features embedded in the raw EEG signals. Also, due to the demanding requirements of some environments (such as jet fighter cockpits), achieving the state recognition in near real-time is critical.

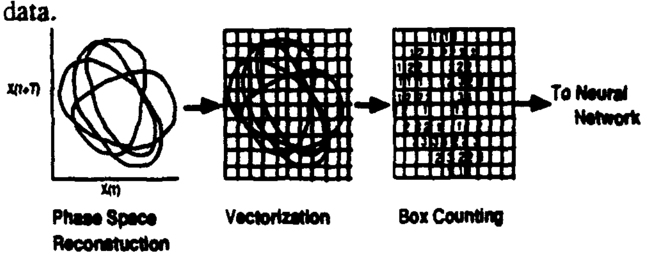
Introduction

The authors began research into physiological Neural Network applications in 1986. Initial studies were conducted utilizing software neural network algorithms in the automatic identification and classification of EEG signals. In these studies, networks performed pattern recognition tasks for transient evoked potentials, particularly for recognizing the presence or absence of a P-300 endogenous response to an auditory tone. The performance of the networks was very promising however, the signals being processed were time synchronized EEG. Networks trained over asynchronous data failed to perform with any degree of reliability. It was apparent that the neural networks were extremely sensitive to time translational effects of the signals. In order to properly identify free running EEG signals, these effects would have to be removed. Translational effects served as a formidable road block to the cognitive mode mapping efforts, until it was discovered that chaos might provide a unique solution to the problem. Phase portraits (or attractors) were able to generate patterns from EEG data that were not susceptible to time translation. It was also discovered that attractor shapes generated from raw EEG data changed with varying mental workload. And finally, the patterns could easily be numerically vectorized for presentation to a neural network. It was hypothesized that by combining the phase space reconstruction with the neural network algorithms, an automatic free running EEG feature recognition system could be developed. It was additionally hypothesized that unique and salient features could be generated by performing specific selected cognitive tasks, and in this way the system might be able to recognize these tasks based on the recorded EEG.

Experimental Methodology

The development of the experimental setup was divided into three phases. The first phase focuses on developing the specialized hardware and software required for proper acquisition and handling of the subject data. Since the analysis procedure pivots on the phase space reconstruction, the EEG amplifiers have to be designed in such a way as to not introduce any phase distortions. This means that all the filters used in the amplifiers have to be phase linear over the range of operation. In this way phase information contained in the EEG is preserved.

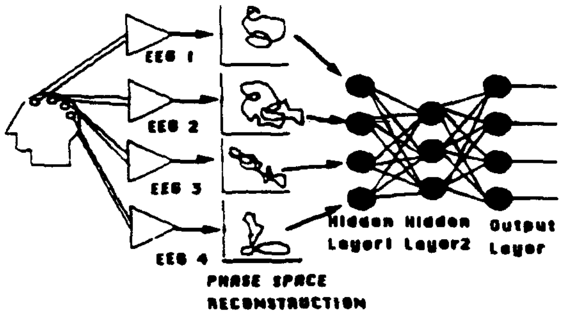
The second phase, and perhaps the most critical, involves the development of software designed to reconstruct and vectorize the phase space of the EEG data.



Phase space reconstruction, part of chaos theory, provides a powerful tool for preprocessing of EEG data in preparation for presentation to a neural network. This preprocessing removes the effects of time translation while retaining amplitude, phase and frequency information. Further, it can be performed in

near real-time unlike Discrete Fourier Transforms. It has been determined empirically that an n-dimensional phase portrait of an EEG signal can generate an input vector that can be easily utilized by neural network paradigms.

The third phase consists of the experimental data collection and subsequent analysis. The experiment consists of collecting EEG data using the multi-site EEG amplifiers from four cranial sites (O1-O2, P1-P2, C1-C2, F1-F2) while the subjects perform selected cognitive tasks. EEG data collected from each of the four electrode pairs are used to generate phase-space portraits (attractors) whose digitized patterns are incorporated into a training set and a test set for input to a neural network. A fifth channel contains information about the task, specifically which classification category it belongs to. Once the data for a given subject has been collected, the neural network is trained on the data off-line. Once training is complete, the network performance is evaluated by using the test set data recorded by the same subject. Further, the trained neural network is evaluated original subject is re-evaluated performing similar tasks while having their mental workload monitored by the neural network in real-time.



In addition, software will be developed for implementation of a unique type of neural network algorithm that changes in size (number of computational elements and their arrangements) while it trains. By altering its architecture during the learning phase, the network will automatically optimize its structure to meet the classification requirements of the input data set.

Preliminary Results

An initial experiment was setup in order to test the system architecture and determine if the analysis tools and analog hardware were operating correctly. A subject was connected to one channel of the complete system at pair locations O1 and O2; reference lead was attached to the subjects right mastoid process. The subject was given three simple "caricature" cognitive tasks to perform. These tasks were: 1) Eyes open, subject alert. 2) Eyes closed, subject alert (Subject was speaking to researchers). 3) Eyes closed, subject performing visualization tasks. The EEG signal from the amplifier was digitized through an A to D converter and pipelined to an IBM PC compatible computer. The computer took the raw data and generated an attractor which was graphically plotted on the screen. The sample rate on the A to D was 120 samples per second, and the attractor consisted of 1200 consecutive points. The former was chosen in respect to the Nyquist sampling criteria, and the latter was chosen arbitrarily. After the sampling was complete, a box counting algorithm was employed to quantize and vectorize the data from the reconstructed phase space (attractor) of the EEG data. This information was stored in a disk file along with the associated tasks type. A total of 32 such vectors were generated and filed (16 for the training set and 16 for the test set). Next, a backpropagation neural network algorithm was trained for approximately 1.5 hours, until the mean square error for the classification was reduced to acceptable levels. After network training, the weight vectors that had been iteratively modified were stored. A second network pre-loaded with the fully trained weights was then used to analyze the test set. For this simple cognitive state classification problem, the network scored 100% correct. That is to say that the network by way of the attractor scheme, could correctly identify the subjects assigned tasks directly from the raw EEG signal obtained from the occipital lobe of the subject. After initial training and evaluation, the subject was recalled and connected to the system in the same way as before except that now, the fully trained neural network was configured to analyze the attractor box count vectors as they were being generated. In this way, we were able to test the near real-time capabilities of the device. It was discovered, that the network was able to correctly classify the EEG signals from the subjects 100% of the time. The classification delay is approximately 15 seconds due to the initial 10 seconds of data gathering and 5 seconds of network feedfoward processing delay. It was also found that the trained network could recognize the subjects EEG days after the initial training took place. The initial findings of the study are exciting and extremely promising, currently the authors are pursuing the extended study utilizing the multi-site data gathering and a more realistic complex cognitive task set.

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